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PRESSURE-PATTERN FLYING

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During the recent war several developments took place in aviation, which led to an increased importance to the air navigator of the close relation between atmospheric pressure and wind. As a result, several methods of navigation and flight planning have been developed which have come to be known under the general title of " pressure-pattern flying ".

The most important of the factors which led to the development of " pressure-pattern flying " were, first the development of the radio altimeter, secondly the increase of long-distance transoceanic flying, and thirdly the increase in the average airspeed, and on the meteorological side the improved network of upper air soundings which permitted the accurate delineation of pressure systems at several levels in the atmosphere.

The pulse-type radio altimeter provides a reasonably accurate measurement of the true height of the aircraft above the surface beneath. Moreover, the pressure altimeter, which an aircraft also carries and which is essentially an aneroid barometer, can be used to measure the atmospheric pressure at the flight level. Thus by comparing the readings of pressure and radio altimeters when flying above a surface of known height such as the sea or a large lake, the navigator is provided with a measure of the atmospheric pressure at a known height. Successive observations enable him to measure the pressure gradient in the direction in which he is flying, and, since it is known that the component of the wind in a perpendicular direction is very closely related to this gradient, the navigator thus has a means of estimating his drift. The high airspeed enables him to ignore the pressure changes taking place during the flight.

The planning of long transoceanic flights where there were no land marks or intermediate airfields also drew attention to the fact that the geographically shortest route is not always the best or even the quickest. Thus out of attempts to improve on the direct route has grown the technique of " single heading flight " and other methods of pre-flight planning intended to reduce the duration of flight. The primary intention is not to get to the destination sooner, but to reduce the fuel load which must be carried and thereby to

increase the pay load. Single heading flight also has the advantage that a course can be calculated on the basis of pressure observations or forecasts at the terminals alone, and the navigator is thus not dependent on wind information over the intermediate regions from which it may not be available. Single heading flight has also been employed to reduce the navigational work necessary in the air by the pilot-navigator of a fast single-seater aircraft.

The basic theory of both altimetric drift determination and single heading flight may be understood by reference to Fig. 1.

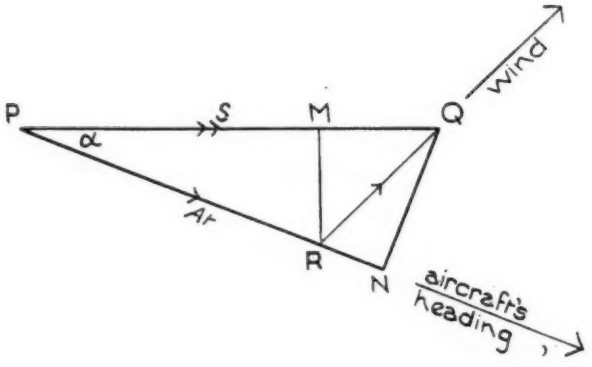


FIG. 1

We consider an aircraft flying on a constant geographical course (constant heading) along an isobaric surface (i.e. with a constant height as indicated by the pressure altimeter) and at a constant airspeed, A.

We consider the progress of the aircraft over a short section of its track PQ (Fig. 1). PR $(= At)$ represents the displacement which the aircraft would have had in still air in the interval t taken to fly from P to Q; RQ represents the displacement due to wind in the same interval, resulting in the net displacement PQ $(= S)$. In Fig. 1, also, NQ represents the component of the displacement due to wind in a direction perpendicular to the aircraft's heading, and we denote this by Z; RM represents the displacement due to wind in a direction perpendicular to PQ, and is equal to vt where v is the component of wind perpendicular to PQ.

Since triangles PNQ and PMR are similar,

$$\frac{QN}{PQ} = \frac{RM}{PR}$$

and thus

$$\frac{Z}{S} = \frac{vt}{At} \qquad \ldots (1)$$

It is well known that, except near the equator, the wind is closely related to the pressure gradient by the geostrophic wind relation which requires that it blows in the direction of the isobars (or contours of an isobaric surface) with a speed proportional to the pressure gradient. Expressed in terms of the slope

of the isobaric surface on which the flight is conducted, this relation may be expressed as

$$V = \frac{g}{2\omega \sin \phi} \frac{H_Q - H_P}{S} \quad .. \quad (2)$$

where g is the acceleration due to gravity
ω is the angular velocity of the earth
ϕ is the latitude
and H_P, H_Q are the heights of the isobaric surface at P and Q.

By combining equations (1) and (2) we obtain the relation

$$Z = \frac{g}{2\omega \sin \phi} \frac{H_Q - H_P}{A} \quad .. \quad (3)$$

If now we write the difference between the readings of the radio altimeter and the pressure altimeter (radio altimeter minus pressure altimeter) as D_1, and D_2 at P and Q respectively, it follows that $H_Q - H_P = D_2 - D_1$, because the pressure altimeter has the same reading at P and Q. This value D is known as the " altimeter correction ".

Equation (3) may then be written in the navigator's usual units (nautical miles for Z, knots for A and feet for D_2 and D_1) as

$$Z = \frac{21{\cdot}47}{\sin \phi} \frac{D_2 - D_1}{A} \quad .. \quad (4)$$

This is the fundamental equation of pressure-pattern flying, since it enables the navigator to calculate his drift from readings of his pressure and radio altimeters. If D, the difference between their readings as defined above, is increasing along his track, his drift is to port in the northern hemisphere, and if decreasing, to starboard. In the southern hemisphere the rule is reversed.

Equation (4) is not only true over a short distance PQ for which we have demonstrated it above; it can equally be applied to a long flight as can readily be shown by integration of equation (4) over the aircraft's track. Provided that the aircraft's course (heading) and airspeed remain constant, the equation gives a method of calculating the total drift (and thus the course to be flown) from the values of D at the terminals only. It is in this manner that it is applied to calculate the course to be flown on a single heading flight.

Although the aircraft's course is maintained constant its track is not a straight line, because the effect of the wind is different over different parts of the route. This is illustrated in Fig. 2, in which the track which would be followed on a single heading flight is shown in conjunction with the pressure distribution on a particular occasion.

When the durations of flights made by single heading methods are compared with those which would have been made on the same occasions by conventional navigation, it is found that the single heading flight plan often results in a quicker flight.

However, it is important to realise that a single heading flight plan does not usually give the most economical flight possible, even at the level at which it is conducted. Under certain circumstances it may even result in a longer duration of flight than a flight along the great circle.

Attention has therefore been directed to methods of choosing the most economical flight path. This is a problem which is still unsolved, and will

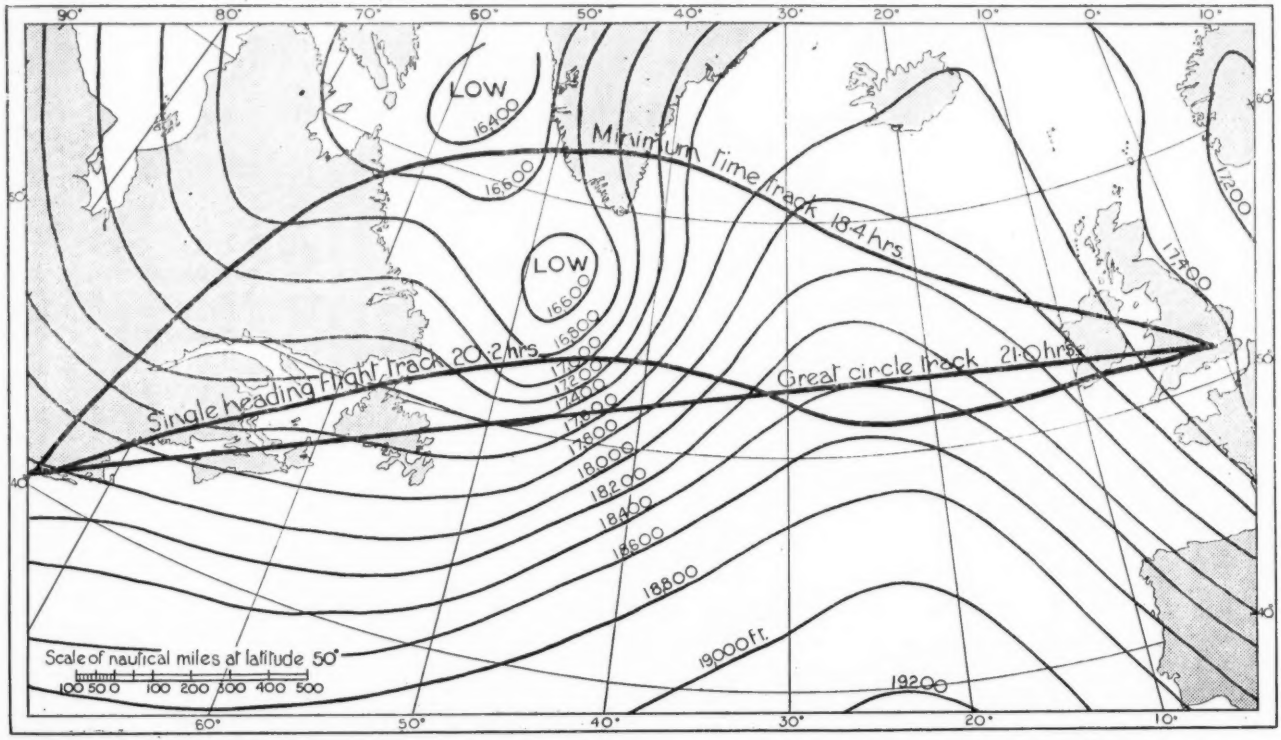


FIG. 2—CONTOURS OF THE 500-MB. SURFACE AT 0400 TO 0600 G.M.T., DECEMBER 4, 1946

This chart also shows the minimum-time track and single-heading flight track for an aircraft leaving London for New York at 0200 G.M.T. with airspeed 200 kt. and flying on the 500-mb. surface. In computing the tracks shown allowance has been made for the changes taking place in the pressure distribution.

always involve a compromise between many factors, such as the fuel economy, the weather expected, the reliability of the forecast, the location of intermediate airfields and many others. However it is interesting to note that many aircraft are now routed across the Atlantic on tracks which take them considerable distances from their direct route, and thereby they reach their destination sooner or obtain better weather.

To demonstrate this Fig. 2 also includes the flight track which would give the least time of any at about the 20,000-ft. level on the occasion for which the pressure distribution is illustrated. By passing north of the active depression an aircraft following this track would avoid the strong head winds further south, and with an airspeed of 200 kt. would reach New York from London with a saving of more than 2 hrs. over a flight along the great circle.

In conclusion it must be pointed out that in deriving the relations which form the basis of single heading flight and altimetric drift determination, several assumptions are made which are not strictly valid. In particular it is assumed that the wind is in accordance with the geostrophic wind equation; a condition which is known not to be strictly fulfilled. The results of the application of the formulae are thus only approximate; but both theoretical consideration and flight trials have shown that the relations are sufficiently close to provide the air navigator with a useful tool, comparable in accuracy with the others at his disposal.

SOME ASPECTS OF THE THEORY OF TURBULENCE

E. J. SUMNER, B.A.

Part I

The phenomenon of turbulent motion is one of everyday occurrence, and like other commonplace experiences it is one that is extremely difficult to define. Owing to the indescribable complexity of the motion it is little wonder that all definitions evade the issue, and either refer to the circumstances in which turbulent flow appears or to the observable effects it produces. Perhaps the best statement of this type is that of G. I. Taylor[1]*, who writes: "Turbulence is an irregular motion which in general makes its appearance in fluids, gaseous or liquid, when they flow past solid surfaces or even when neighbouring streams of the same fluid flow past or over one another". A great deal of progress has been made in the elucidation of the problem under laboratory conditions (by means of wind-tunnel experiments, etc.) but in the atmosphere, with its variable boundary surface and changing temperature conditions, there are many further complications, and as yet we are far from solving it.

The aim of this article is to emphasise and discuss a few recent qualitative ideas in the study of atmospheric turbulence as well as to give a brief account of at least one special theory. I have made free use of ideas and forms of words to be found in the general literature of the subject, with particular reference to a paper by C. H. B. Priestley and W. C. Swinbank[2], and have embedded them, so to speak, in a critical commentary of my own. The treatment is necessarily sketchy, but it is hoped that it will help to clarify some of the difficulties to be overcome before the problem is understood, and to suggest some useful ideas to the practising meteorologist.

* The index figures refer to the references on p. 82.

Eddy diffusion, mixing and transport.—The earlier theories of turbulence were based on a direct analogy with the kinetic theory of gases. The irregularities in turbulent motion were compared to the molecular agitation which gives rise to such physical properties of the fluid as pressure, temperature and viscosity. Just as gaseous diffusion was explained by the motion of the constituent molecules, the changes in the average distribution of certain atmospheric properties were thought of, and still are, as resulting from the movement of elementary volumes or particles of air, small by everyday standards but large by comparison to the mean free path of the molecules, forming part of an eddy. This process was called, appropriately enough, eddy diffusion. No definite meaning could be ascribed to the word " eddy " in all cases, but in as far as it conveyed the idea of movement in accordance with a set pattern it corresponded roughly with observations of certain types of fluid motion.

Eddies are the visible agents in the spread of transferable properties in a fluid medium. They are of all sizes, the smaller ones often forming part of and moving with the larger, and are constantly being formed and dissipated again. Although the details of the motion are conveniently ignored, the concept of eddy diffusion is a necessary preliminary to our understanding of the mixing process. Ultimately, mixing is a comparatively slow process of molecular diffusion, but it can be enormously facilitated by the bodily movement of lumps of fluid constituting eddies, and by their gradual mechanical disruption. An eddy, considered as a stationary " whorl " only losing its excess temperature, say, by molecular diffusion through its boundaries, would not be nearly so good a transporter of heat as one that moved as a whole, and at the same time disintegrated, thereby presenting a much greater surface area to the colder environment.

But, however complete the picture, we are still faced with the difficulty of describing in mathematical terms the evolution and decay of an eddy, and, up to the present, no theory of turbulence pretends to be a theory of the diffusion of or by eddies as such. In order to formulate any sort of theory at all, simplifying assumptions must be made. Some of them are at variance with the known physical properties of fluids, while others are occasioned by lack of observational knowledge. Before proceeding it is necessary to analyse the idea of diffusion more completely.

The two basic concepts are transport and mixing. The motion of an elementary volume of fluid can be considered abstractly in itself, but in practice the simultaneous transport of certain properties cannot be dissociated from molecular mixing, and exchanges of property across the boundaries of the particle are always going on. Mixing, in this sense, is a continual process, and although this has been clearly recognised there is only one theory which takes it into account, namely that of O. G. Sutton[3] who developed Taylor's theory of diffusion by continuous movements[1] and applied it to the atmosphere. Even in Taylor's theory molecular mixing has no effect on the diffusive power of turbulent motion; it is merely concerned with the mixing due to the relative motion of individual fluid particles whose properties remain invariant indefinitely. The, so called, mixing-length theory given subsequently also approached the problem in this manner, and presents an idealised picture of the motion under discussion.

The real atmosphere.—In a turbulent atmosphere the wind velocity is naturally subject to continual variations, both large and small, which may readily be seen on any anemograph trace. A large proportion of the fluctuations near the ground seem to have a period of about one second, though almost any period may occur from a fraction of a second to many days. One would expect other properties to show similar irregularities and a glance at a typical autographic trace confirms this. As yet, except for wind velocity, instruments of sufficient sensitivity have not been developed to follow the finer details of these microvariations, but such variations undoubtedly occur.

We cannot hope to describe the irregularities of the turbulent state in detail, and, after all, the average distribution of various properties in space is of greater practical importance. Yet we cannot afford to ignore reality altogether, and the principal defect of earlier theories was the over-simplified notions of the atmosphere that they were based on. Priestley and Swinbank have remedied this to a certain extent, and the following is a generalised treatment of their paper.

Mathematical theory.—In the absence of any adequate concept of mixing as a continual process one is forced to accept the limitation of considering moving elements of a fluid as particles which preserve their identity in moving from one point to another. If θ stands for the amount of a transferable property of the atmosphere per unit mass, we may denote its mean value by $\bar{\theta}$, so that $\theta = \bar{\theta} + \theta'$. For velocity, θ' is simply the " eddy velocity " of Osborne Reynolds, and this convention can be extended to other properties. Thus one can speak of the " eddy temperature ", for example, but for reasons given later this is not completely satisfactory, and, following Priestley and Swinbank, the expressions " temperature anomaly ", " moisture anomaly ", etc., will be used for the departure of temperature, moisture content, etc., from their mean values. The arithmetic mean of the property in question is normally taken either with regard to time at a fixed point, or over a given area at a particular instant of time.

The flux across a small element of surface area δS is equal to $\rho w \theta \delta S$ where w is the wind velocity normal to δS, and ρ is the density of air, so that the average flux per unit area per unit time is $\overline{\rho w \theta}$, the mean being taken over the surface at a fixed time. If this surface is an isobaric surface then $\overline{\rho w} = 0$, since there can be no net transport across it, and the flux may be written $\overline{\rho w \theta'}$. In the atmosphere isobaric surfaces are for all practical purposes plane horizontal surfaces, and we may therefore represent the vertical flux by the equation $F = \overline{\rho w' \theta'}$, where w' is now the vertical component of the eddy velocity, assuming there is no mean vertical velocity (i.e. $\bar{w} = 0$). Horizontal mean gradients are normally negligible by comparison with vertical gradients, so that $\bar{\theta}$ and F may be taken as functions of z, the height, and t, the time, only, and written $\theta\ (z, t)$ and $F\ (z, t)$ where necessary.

Considering a small volume between two isobaric surfaces of unit cross-section and thickness δz, the flux across the lower one is F and across the upper $F + (\partial F/\partial z)\delta z$ to the first order, and the mean accumulation (i.e. inflow minus outflow) in the elementary volume is $-(\partial F/\partial z)\delta z$ per unit area, per

unit time. The amount of the property between the two planes is $\rho\theta\delta z$ per unit area, so that $\{\delta(\rho\theta)/\delta t\}\delta z$ is the mean rate of change per unit area per unit time. Therefore

$$\overline{\frac{\delta}{\delta t}(\rho\theta)\delta z} = \frac{\delta}{\delta t}(\overline{\rho\theta})\delta z = -\frac{\delta F}{\delta z}\delta z,$$

and the fundamental equation becomes

$$\frac{\delta}{\delta t}(\overline{\rho\theta}) = -\frac{\delta}{\delta z}\overline{(\rho w'\theta')}.$$

Now the atmosphere may be assumed to be homogeneous and incompressible over a limited depth without appreciable error, i.e. ρ is constant, hence

$$\frac{\delta\overline{\theta}}{\delta t} = -\frac{\delta}{\delta z}(\overline{w'\theta'}) \qquad .. \quad (1)$$

Since $\overline{w'\theta'}$ is not directly measurable as yet, we must express it more conveniently before a solution is possible. An elementary particle of fluid may be considered to have originated at a vertical distance l below the datum level, where the mean value of the property is $\bar{\theta}(z-l, t)$, which is approximately equal to $\overline{\theta} - l\delta\overline{\theta}/\delta z$, l being positive. The actual value of the property at this level is $\overline{\theta} - l\delta\overline{\theta}/\delta z + \theta''$ where θ'' is the anomaly there, and since it is conserved during the passage of the particle to the datum surface, $\theta' = -l\delta\overline{\theta}/\delta z + \theta''$. This equation is only valid if l is small, or if the higher derivatives of $\overline{\theta}$ above the first are small, and provided the time of travel is so short that no significant change in the mean property takes place in the meantime. Substituting for θ' in the equation of flux, we get

$$F = -\overline{w'l}\frac{\delta\overline{\theta}}{\delta z} + \overline{w'\theta''} \qquad .. \quad (2)$$

and equation (1) becomes

$$\frac{\delta\overline{\theta}}{\delta t} = \frac{\delta}{\delta z}\left(\overline{w'l}\frac{\delta\overline{\theta}}{\delta z} - \overline{w'\theta''}\right) \qquad .. \quad (3)$$

$$= \frac{\delta}{\delta z}\left(K_\theta\frac{\delta\overline{\theta}}{\delta z}\right) \qquad .. \quad (4)$$

where

$$K_\theta = \overline{w'l} - \frac{\overline{w'l}}{\frac{\delta\overline{\theta}}{\delta z}} \qquad .. \quad (5)$$

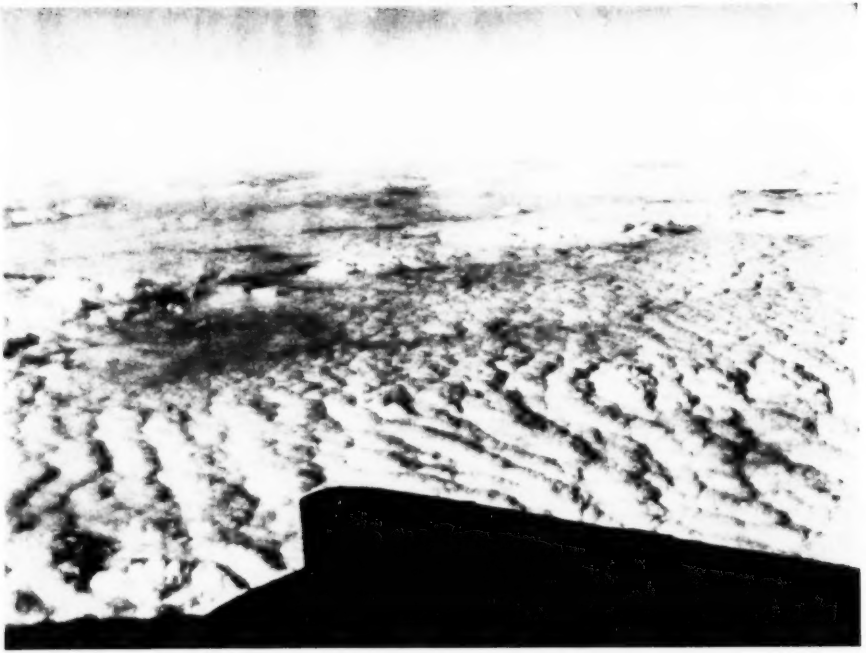
K_θ is known as the coefficient of eddy diffusivity for the property under consideration. Equations (4) and (5) do not apply for $\delta\overline{\theta}/\delta z = 0$, and when this is so we shall have to revert to equation (3). It is interesting to note that according to this equation there can still be a flux of the property even when there is no mean gradient, although in this case molecular diffusion would soon smooth out the anomalies making both $\overline{w'\theta''}$ and F tend to zero simultaneously.

In the old classical theory the level of origin of an elementary particle was conveniently chosen as that at which the property had a value equal to the mean value of its environment so that $\theta'' = 0$, and K_θ reduces to the more familiar form $\overline{w'l}$. But there is no reason to suppose that the property associated

[*To face p.* 80

SMALL CUMULUS CLOUD OVER ENGLAND AND FRANCE LEAVING THE ENGLISH CHANNEL CLEAR

Photograph taken from 14,000 ft. at 1058, June 27, 1944.



CUMULUS HEADS PROTRUDING THROUGH ALTOCUMULUS SHEET
Photograph taken over Paris from 29,000 ft. at 1545, October 2, 1943.

with an element of fluid ever had a value equal to the mean value of its environment, or if it had, that l is a small distance. Obviously the particle could have had a very varied and lengthy career from the time it last had this property to when it reached the datum level (which it might have traversed in opposite directions more than once) and the lifetime of a particular volume may not be short by comparison with the time scale of any net average change of the mean property at any level. Also, a long time of travel implies less likelihood of an element preserving its properties unchanged; the only thing that makes the theory anything like tenable is shortness of travel both with respect to time and vertical distance. As Priestley and Swinbank pointed out, it was more logical to regard the level of origin as that level at which the eddy was last at rest in the vertical before penetrating the datum surface.

In defining such parameters as $\overline{w'l}$ and $\overline{w'\theta''}$ no reference has been made to the size of the area over which the mean is taken. However there are necessary limitations of size, since the area must not be so small as to exclude the passage of a representative number of eddies, i.e. it must be large compared with what one might call the " effective " eddy diameter, and it must not be large enough to include significant horizontal variations in the mean property. It is one of the conditions of formulation that horizontal gradients are non-existent, and when they do occur sideways eddy diffusion makes its contribution to the flux. We have, in effect, reduced atmospheric motion to two dimensions, one of space and one of time, and for ordinary purposes this suffices. The above equations apply to any fluid medium for which the assumptions hold—the oceans as well as the atmosphere—and in practice either " space " means or means with respect to time at a fixed point, which are the ones normally available, may be used.

Mixing and transport lengths.—The length l introduced in the previous section is often called a " mixing length ", although this is evidently a misnomer. Up to now no reference has been made to mixing at all, in fact, it is explicitly assumed that the properties of a fluid are carried without mixing in the sense already referred to; l is more accurately a " transport length ", and this name will be retained in what follows except where convenience of reference to current usage prohibits it. Strictly speaking a mixing length should be the length of the path, traversed by an elementary volume of fluid from the point of origin to where it has completely mixed with its environment. This length, as such, remains unchanged whether we conceive of the process as one in which the element retains its identity until the end of its path and then mixes " instantaneously " with its environment, which is the sort of process envisaged in transport-length theories, or as a continual process of mixing until it is indistinguishable from its surroundings.

However, there are several difficulties in this definition. First, what is meant by the level of origin ? Probably the best answer is that given by Priestley and Swinbank, *viz.* that it is the level at which the particle was last at rest in the vertical. Secondly, when is complete mixing effected ? The best answer seems to be, when the property of an element first reaches a value equal to the average value (horizontally) of its environment at that instant. If the motion were suddenly arrested at this end point there would be no ultimate change in the value of the property due to further (molecular) mixing. It will be noticed that both at the level of origin ($w' = 0$) and at the end point ($\theta' = 0$),

$\rho w'\theta'$ is zero, and the moving element contributes nothing to the total flux at the two levels. The scheme corresponds roughly to the life-cycle of an eddy considered as an agent of diffusion, since initially an element would begin to move under the influence of a newly formed eddy, or if it were already moving horizontally in an eddy it would only become effective in the vertical transfer when it does start to move vertically, and the final extinction of the anomaly would often mark the decay of an eddy. But this interpretation of mixing length is inadequate inasmuch as it does not describe every phase in the life of a moving particle. Even after it has acquired the mean property of its environment a particle can still continue to rise and be subject to further mixing before either coming to rest again in the vertical or acquiring a fresh mean value at another level. Thus it is evidently possible to define several types of mixing length from this point of view alone.

In the transport-length theory given above we are only concerned with the level of origin of an elementary volume of fluid, not its ultimate history, and the chief difference between the older classical theory and that of Priestley and Swinbank is in the definition of this level. In the former a particle is concerned as originating with the mean property of its environment, and in the latter it starts from rest in the vertical having properties which differ from the properties at its level. Since the elementary particles move with relatively large masses of air in an individual eddy it is obvious that, during its passage to the level of reference, molecular mixing tends to destroy the existing anomalies. Similarly for the bigger eddies, a large mass may be considered to have come from a common level, and the sideways mixing due to diffusion by smaller eddies, which has been ignored in the theory, helps to smooth out the large-scale initial differences during transit. In other words, an elementary volume may be considered as effectively having started at a level with more or less uniform properties horizontally, and it is to be expected that the truth lies somewhere between the two theories. But the differences between the mean values of the properties associated with the largest and most effective eddies still have to be reckoned with, and, in spite of the general loss or gain of property across the boundaries, must be allowed for in the formulations. The second term in the flux equation is undoubtedly real, and represents a new approach to the problem of atmosphere turbulence. A fuller discussion of its significance and advantages will be given in the next article.

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METEOROLOGICAL OFFICE DISCUSSIONS

The third Monday evening discussion of the present session was held in the lecture theatre of the Science Museum on February 23. Mr. O. M. Ashford opened the discussion, which dealt with an unpublished paper by Dr. R. Schulze on the requirements and classification of radio-sondes.

Mr. Ashford explained that the paper was prepared about the end of the war as an introduction to a series of papers by officers of the German Marine Observatory, Greifswald, on the application of radio-sondes to meteorology and ballistics. The first part of the paper dealt with the range and accuracy requirements of radio-sondes for various applications. Two values were given under each heading, an " acceptable " value and a " desirable " value. For synoptic work the desirable accuracy was stated as $\pm$ 0·4°C. in temperature, $\pm$ 3 per cent. in relative humidity and the equivalent of $\pm$ 100 m. height in pressure (i.e. $\pm$ 3 mb. at ground level to $\pm$ 0·2 mb. at 20 Km.). The difficulty of meeting these requirements was emphasised by pointing out that the German standard for a precision electrical instrument was only $\pm$ 0·5 per cent. of the range, which would correspond to $\pm$ 0·5°C. and $\pm$ 5 mb. in temperature and pressure for a radio-sonde.

The remainder of the paper described a system of classification of all known radio-sondes into temperature-sondes (giving pressure, temperature and humidity), wind-sondes (giving wind) and weather-sondes (pressure, temperature, humidity and wind), with further subdivisions into active- and passive-sondes, and mechanical- and electrical-sondes.

In discussing the paper Mr. Ashford said that there was a need for a clear statement of accuracy requirements by upper air analysts. Careful distinction should be made between probable errors and 90 per cent. errors, and between systematic and random errors. From the instrument designers' point of view there were numerous interesting possibilities of improving the accuracy of radio-sondes, such as the use of a hypsometer for measuring pressure, but the vital question of cost had always to be borne in mind. The possibility of applying corrections for instrument lag and radiation errors ought to be investigated.

In the discussion which followed, the Director mentioned the work on a sonic velocimeter being carried out at Oxford, and pointed out that a limit to the desirable accuracy was set by the variability or patchiness of the atmosphere. Dr. Harrison mentioned the attempts that were being made to assess the accuracy of radar methods of measuring upper winds. Dr. Scrase remarked that the question of desirable accuracy had been raised at the I.M.O. Conference at Washington but no definite conclusions had been reached. Prof. Sheppard preferred the use of 90 per cent. errors rather than probable errors, and suggested that progress might be made by the introduction of different types of instruments, e.g. a radio-sonde which gave out a signal when it reached standard pressure levels, the height being measured by radar. Mr. Gloyne thought that a certain amount of instrument lag was desirable, as it smoothed out the small-scale variations. Mr. Oddie, however, thought it better to record the fine structure and apply the smoothing subsequently as desired.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society, held at 49, Cromwell Road, on February 18, with Prof. G. M. B. Dobson, President, in the Chair, the following papers were read:—

R. C. Sutcliffe—A contribution to the problem of development.

This paper grew out of an earlier one by the same author (1939) in which it was argued that development in the atmosphere consists of a vertical distribution

of divergence and convergence such that the integrated divergence, defining the surface pressure tendency, is a small residual of opposing contributions at different levels. It was then inferred that development could be diagnosed by finding the difference between the divergence at the surface and some upper level. Since geostrophic motion is non-divergent it is to be expected that a study of the field of acceleration difference between two convenient levels (associated with departures from geostrophic flow) would indicate the nature of the development. In the present paper Dr. Sutcliffe developed the same general argument in terms of the change of vorticity, which is closely connected with the curl of acceleration.

In passing, he defined " subsidence " and " ascent " as states in which dp/dt is positive or negative respectively, and pointed out that either may extend through the whole troposphere into the stratosphere even though the divergence changes sign at some intermediate level. He also remarked that in many cases a study of the dynamics of the surface motion alone is insufficient to indicate the nature of significant developments. The appearance of abnormal weather in complex thermal structures may be expected without indications from surface observations (including pressure tendencies).

His fundamental equation is

$$l\,(\mathrm{div_p}\mathbf{V} - \mathrm{div_p}\mathbf{V}_0) = -V'\frac{\partial}{\partial s}(l + \zeta + \zeta_0)$$

in which the left-hand side denotes the relative (isobaric) divergence between two pressure levels (> 0 for cyclonic and < 0 for anticyclonic development), V' is the relative wind (or shear) between the same two levels, ζ and ζ_0 are the respective vorticities, l is the Coriolis parameter $2\omega \sin \phi$, and $\partial/\partial s$ denotes differentiation in the direction of shear. It is obvious from the equation that there can be no development without shear. The formula is derived from the normal tendency equation by means of the intermediate equation

$$l\,(\mathrm{div_p}\mathbf{V} - \mathrm{div_p}\mathbf{V}_0) = -\mathbf{V}.\,\nabla_p(\zeta + l) + \mathbf{V}_0.\,\nabla_p(\zeta_0 + l) - \frac{1}{l}\left(\frac{\partial}{\partial t}\right)_p \nabla_p{}^2 h',$$

where h' is the " thickness " between the isobaric surfaces. Assuming that the motion is quasigeostrophic, i.e. the wind nearly balances the pressure gradient, the approximate equation

$$\zeta = \frac{1}{l}\nabla_p{}^2 h = \frac{1}{l}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right)_p h$$

is deduced, h being the absolute height of the pressure level, the suffix, p, implying differentiation at constant pressure. These two links lead directly to the first equation, assuming, among other things, that the direction of wind shear is invariant with height over the layer, that there is no vertical motion, and that the effect of adiabatic and direct heating and cooling processes on the resulting thermal field, may be ignored by comparison with advection. The author recognised that the latter two effects were definitely significant in certain situations.

In applying these ideas to forecasting it is formally possible to determine the important relative divergence factor for the thickness layers between the 1000-mb., 750-mb., 500-mb., and 300-mb. surfaces, so as to get some indication of the development taking place. Subject to the assumptions made, the prob-

lem reduces to that of determining the quantity $(\partial^2/\partial x^2+\partial^2/\partial y^2)h$ on the various charts, representing the results by isopleths and then estimating the value of the gradient along the direction of the shear vector. Dr. Sutcliffe stated that such a procedure had been tested quantitively over a considerable period with some promise, and he hoped next to undertake a series of synoptic studies. The method did permit of an estimate of the development between existing and forecast charts and did allow of a further rough extrapolation, whereas the old method based on observed tendencies did not. He concluded by saying that his ideas did not represent the complete story, but since the arguments and deductions were susceptible both to physical interpretation and practical test they might be of value. With experience, a forecaster should be able to arrive at something better than almost pure empiricism.

C. H. B. Priestley—Dynamical control of atmospheric pressure.

This paper, in the absence of the author, was read by Prof. P. A. Sheppard. It is mainly concerned with the movement of pressure systems without distortion and development, which amounts to finding the surface pressure tendencies throughout the field of flow under these conditions, and seeks, like the first, to explain why the realised pressure tendency invariably emerges as a small residual of its much larger primary components. His thesis is that the field of flow determines the pressure change, but itself depends dynamically on the instanteous pressure-tendency field. It is this mutual interaction between the two fields which constitutes the brake or control on the mutability of the pressure field.

The author shows that purely geostrophic motion implies very large tendencies for north-south flow, which are not compensated by vertical velocities of the order found in nature, and he is therefore led to consider the changes associated with a geostrophic flow. He ignores those due to acceleration along the path (unlike Sutcliffe), vertical velocity and surface friction and merely discusses the effect of deviations due to curvature of the path. Thus the true wind is replaced by a suitably defined gradient wind, and the tendency equation is expanded in terms of the divergence of gradient momentum. An appendix to the paper gives a new interpretation to the gradient wind which is adopted throughout.

A number of applications are made with the object of explaining the broad features of the translation of idealised pressure systems, and many practical forecasting rules are deduced, some of them already well established. In addition, an indication is given as to how the principle of control may be used to clarify some problems of development, the extent of which depends on the asymmetry of the pressure system about its meridional axes. Finally, the author acknowledges that deviations from the gradient wind may be large at times and states that he hopes to make a closer study of them later.

J. S. Sawyer—Notes on the theory of tropical cyclones.

Mr. Sawyer started by describing the conventional picture of the development of tropical storms, and said that the chief difficulty is to explain the eviction of air from the upper levels of the cyclone after the initial rise of pressure had been equalised and the circulation had become cyclonic at all levels. In his paper he considers the condition under which continued outward motion is possible in a circular vortex, and arrives at the following criteria for the formation of a revolving storm, viz :—

(*a*) A lapse rate which will give rise to vertical instability and the development of cumulonimbus cloud.

(*b*) A distribution of circulation at some level aloft such that anticyclonic circulation increases outward at a rate exceeding a certain value.

(*c*) A distribution in the vertical of horizontal rotation such that the cyclonic distribution decreases with height.

The surface vortex is characterised by the relation vr=constant (r being the distance from the centre and v the tangential velocity), which obviously must break down towards the centre. The author suggests that very large values of v are prevented by the turbulence due to horizontal wind shear, and it is this effect which is responsible for the calm " eye " of the storm. The relation between tropical cyclones and fronts is briefly discussed in conclusion.

In the ensuing discussion all three papers were taken together ; Prof. Brunt, Prof. Sheppard, Mr. Douglas, Mr. Durst and Mr. Eady were the principal speakers. Attention was drawn to the large number of approximations and assumptions made in order to treat atmospheric flow mathematically, although this was as much a source of congratulation for the brilliant way in which it had been done, as an object of criticism. Prof. Brunt did not consider the use of geostrophic winds could give accurate results, while Mr. Douglas could see no improvement, from a practical forecasting point of view, without an understanding of fundamental atmospheric processes, although he considered the insistence of Dr. Sutcliffe on a study of the changes in the thermal field—thickness-line technique, and vector shear—represented a real advance. He agreed that much of the movement of pressure systems was in the nature of development. Mr. Durst shared the general scepticism of the qualitative results to be expected from the papers, and thought that the application of electronic devices to numerical solution of the equations of motion may ultimately be necessary. Perhaps the most illuminating remarks of the evening came from a mathematician, Dr. McVittie of King's College, London, who had recently examined the equations of motion used by meteorologists. He pointed out that the earth was round, not flat, that air was a gas, not a liquid, and suggested that a more realistic scheme of co-ordinates should be adopted and the fact of atmospheric compressibility taken into account.

In replying, Dr. Sutcliffe thought that such quantities as divergence and vorticity, which were first derivatives, were not appreciably affected by using Cartesian co-ordinates. Mr. Sawyer, while agreeing with Dr. McVittie, said that simplifications were necessary to reduce the complexity of dynamical problems. His own treatment was only intended to give an indication of the way in which a tropical cyclone might evolve.

THE ROYAL SOCIETY

The paper, " Correlation between climate, forest composition, prehistoric archaeology, and peat stratigraphy in the Somerset Levels " by A. R. Clapham and H. Godwin, F.R.S., read before the Royal Society on February 19, gave a striking example of the possibility of linking together botanical and archaeological evidence to reveal changes in climate.

The area considered in this paper is that between the Mendip and Polden Hills in central Somerset. The area is a plain called the Somerset Levels floored

by clay which filled up much deeper valleys during a transgression of the sea in late glacial times. On this clay there grew extensive peat bogs which are now being worked for fuel.

The authors cut sections in the peat and found two layers of varieties, *Cladium-Hypnum*, *Aquatic Sphagna* and *Scheuchzeria*, known to grow under flooded conditions with the variety, *Sphagnum Calluna-Eriophorum*, growing under drier conditions, below and between them. At the lower level in question there occur wooden trackways buried in the peat running between areas of high ground. These trackways are made of substantial logs supported by long stakes driven into the peat below and held by longitudinal stringers. The cut ends of the logs bear marks of the size and shape appropriate to the axes made in late Bronze Age times. Further evidence for the culture in which the tracks were constructed was provided by a bronze spearhead of the same period found by a peat digger at the same horizon. This places the swamping at about 500 B.C. This is the time at which the cold wet period, known as the sub-Atlantic commenced.* The trackways themselves are, the authors pointed out, confirmatory evidence of swamping since they are not needed for safe crossing of normal peat and must have involved a great deal of effort.

The higher layer of the variety of peat growing under flood conditions was dated archaeologically by a Romano-British interment just above it and is considered by the authors to have formed about A.D. 250.

Further evidence in support of their arguments was provided by analysis of the pollen grains found in the peat. This analysis showed a great decrease at the flooding levels in the proportion of the pollen of cereals and of weeds which grow on cultivated ground.

LETTER TO THE EDITOR

Development of cumulus over fires

The letter in your issue of June 1947, p. 139, describing the growth of cumulus over a tar fire seems to suggest a rarity for what is a very common process, in the tropics especially. The finest clouds of this type are over forest fires ; a beautiful picture of one was given in this magazine for April 1939. The rising columns of heat and smoke over the countless bush fires of tropical grass lands in the dry season often develop plumes of cumulus, the bluish haze of the smoke changing to the dazzling white of the cloud in a way that is as beautiful as it is instructive. A much smaller conflagration may suffice ; in the tiny island of Agaléga in the tropical Indian Ocean (10° 26′ S., 56° 40′ E.) I have seen a large patch of cumulus growing at the top (altitude some 3,000-4,000 ft.) of the column of smoke from a small native bonfire of garden refuse ; this naturally tends to occur about midday on a sunny day in the rainy season, when the sluggish air is excessively moist and hot (physiologically), and the lapse rate is very steep.

W. G. KENDREW

Oxford, March 3, 1948.

NEWS IN BRIEF

Mr. Gordon Manley M.A., M.Sc. has been appointed to the University Chair of Geography at Bedford College, University of London.

* BROOKS, C. E. P.; Unsolved problems of climatic change. *Met. Mag., London*, **76**, 1948, p. 128.

NOTES AND NEWS

Admiral Fitzroy's clock

During the war the Meteorological Office received an interesting memento of its first Director, Admiral Fitzroy (1855-1865), in the form of a clock which was presented to Admiral Fitzroy by the Minister of Marine and Colonies of France.

On his appointment as Director, one of Admiral Fitzroy's first steps was to organise a system of storm warnings for ships. In doing this he was taking advantage of the recently introduced electric telegraph, prior to which such a system of warnings was, of course, impossible. Admiral Fitzroy decided to share the advantage of his warning system with the French, and he made arrangements for the warnings to be telegraphed to Paris, whence they were distributed for the benefit of the French Navy, merchant navy and fishing fleets. It was in recognition of the services thus rendered that the French Government presented Admiral Fitzroy with the clock which forms the subject of this note.

The clock is a beautiful specimen of the travelling clocks of that period, and its general appearance can be seen from Fig. 1. The movement is contained in a gilt case standing 7½ in. high, with bevelled glass panels forming the sides, and bearing richly chased steel figures on the corner columns. In addition to the ordinary dial, the clock has subsidiary dials showing the day of the week, day of the month and month of the year. It also has an alarm and repeater mechanism which strikes the last hour and quarter on pressing a stud on the top of the clock case.

The glass plate which forms the top of the case is engraved with the following inscription :—

" Offerte par le Ministre de la Marine et des Colonies au Vice-Admiral Robert Fitzroy, Esq., Chief of the meteorological department of the Board of Trade, pour services rendus à la Marine Impériale, 1864."

This beautiful and historic clock was bequeathed to the Meteorological Office by a daughter of the Admiral, Miss Laura Fitzroy, who died in 1943. It forms a treasured memento of a great man, who was not only the first Director of the Meteorological Office, but whose energy was in large measure responsible for its formation.

N.K.J.

New York snowstorm, December 26, 1947

The effects of the great snowstorm in New York on December 26, 1947, will be familiar from newspapers and newsreels.

We welcome the opportunity of giving, by courtesy of the U.S. Weather Bureau, an account of the meteorological conditions which gave rise to the snowfall. The Weather Bureau selects each month an interesting or unusual situation for detailed analysis, and publishes the results with charts on the back of its *Daily Weather Maps*. Nearly all the information and all the maps which follow are taken from analysed Series No. 36 published on the back of the *Daily Weather Maps* of February 9 and 10.

The total fall of snow in New York city during the storm was 25·8 in. and at places in the surrounding country it reached 30 in. Such a total amount is not extremely rare in a single storm, though fortunately it does not often fall on a great city, but the rate of fall, 1·8 in./hr. from 5 a.m. to 7 p.m. was quite exceptional.

[*To face p.* 88

ADMIRAL FITZROY'S CLOCK

To face p. 89]

ADMIRAL FITZROY'S CLOCK, SHOWING INSCRIPTION

Fig. 1 shows the synoptic situation at 7.30 p.m. (eastern standard time) on December 25. The depression centred off Cape Hatteras had formed over Alabama on the 23rd and moved north-eastwards to the Atlantic. A nearly stationary front extended north from the depression, and on this front there formed a small " wave " which soon deepened and was a prime cause of the storm. Another depression was centred over the Great Lakes.

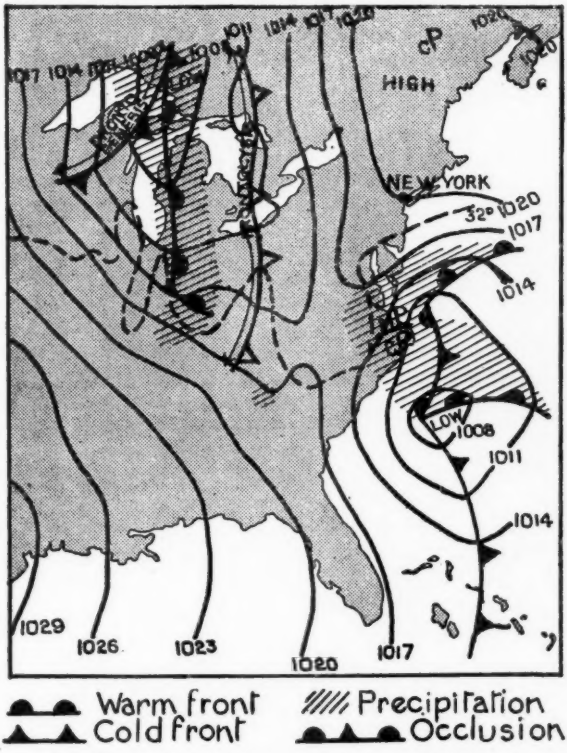

FIG. 1—SYNOPTIC CHART 7.30 P.M. E.S.T., DECEMBER 25, 1947

At 7.30 a.m. December 26 (Fig. 2), the wave, with a central pressure only some 5 mb. less than on the previous evening was centred some 150 miles south-east of New York. The original depression off Cape Hatteras had by this time moved away eastwards. The Great Lakes depression had also moved eastwards. Snow began to fall in New York in the early hours of the morning and at the time of the chart it was snowing heavily. The 500-mb. contour chart, for 10.30 a.m. December 25, Fig. 3, shows that at that level, about 18,000 ft., the dominant feature was a depression over the Great Lakes due to a combination of rather low surface pressure and very cold air. At 500 mb. the wind over the Atlantic coast was southerly about 50–70 m.p.h. The Weather Bureau analyser considered this strong southerly wind aloft to have caused the Atlantic depression to move north-north-east, so bringing the snow to New York, instead of, as would normally be expected, moving to north-east.

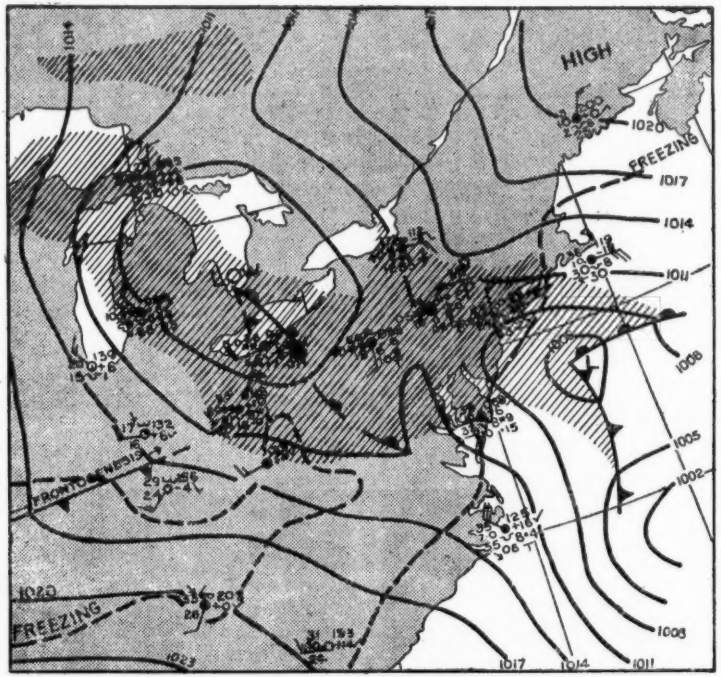

FIG. 2—SYNOPTIC CHART, 7.30 A.M., E.S.T., DECEMBER 26, 1947
For explanation see Fig. 1.

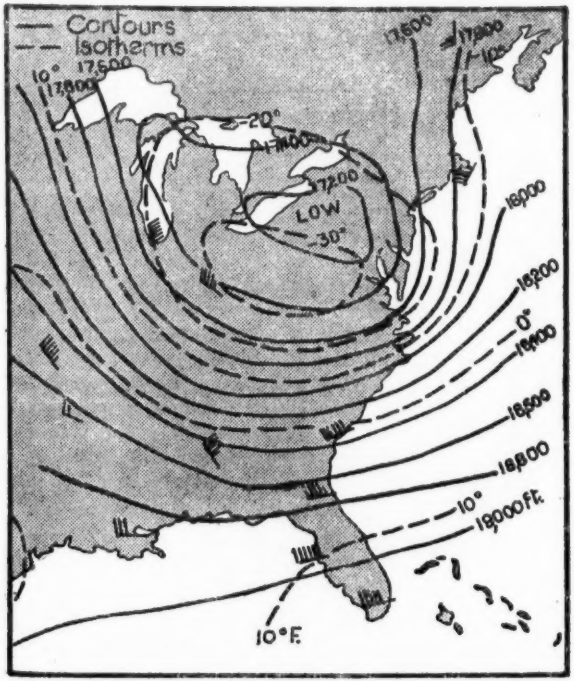

FIG. 3—500-MB. CONSTANT-PRESSURE CHART, 10.30 A.M., E.S.T., DECEMBER 26, 1947

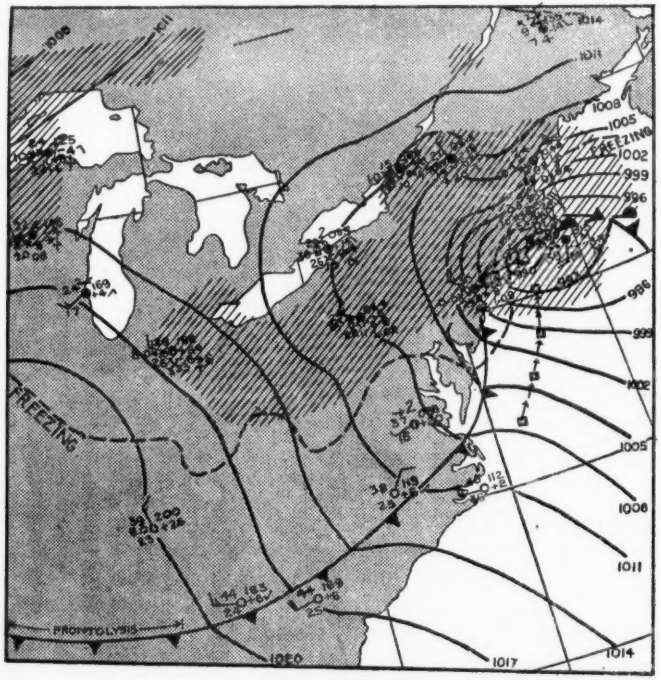

FIG. 4—SYNOPTIC CHART, 7.30 P.M., E.S.T., DECEMBER 26, 1947
For explanation see Fig. 1.

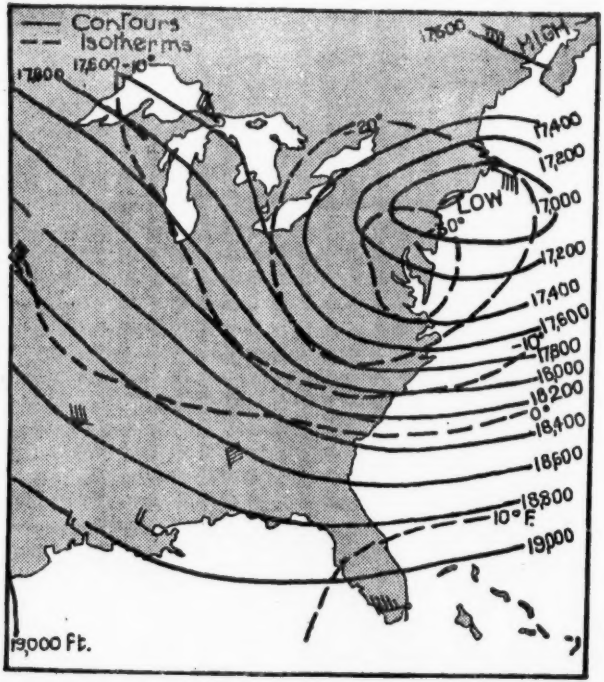

FIG. 5—500-MB. CONSTANT-PRESSURE CHART, 10.30 P.M., E.S.T., DECEMBER 26, 1947

Fig. 4 shows the depression at 7.30 p.m. December 26 centred very near New York with a warm front to the east just along the coast. The temperature difference across the front at the surface seems to have been about 10°F. The tip of the warm sector, round which precipitation was particularly heavy, moved near New York. The depression over the Great Lakes had by this time nearly filled up appearing only as a bulge in the isobars. The centre of low pressure at 500 mb., Fig. 5, was by 10.30 p.m. December 26 roughly over the Atlantic depression.

The wind was below 30 m.p.h. for most of the period of the snowfall reaching a maximum of 30 m.p.h. Temperature was between 24° and 30°F. The whole system looks rather weak for such a heavy fall. It is clear the warm-sector air at a moderate altitude must have been very warm and damp but unfortunately there are no upper air observations from the warm sector. Owing to the relatively light winds drifting, though serious enough with drifts 6 ft. deep, did not produce the 20-ft. drifts of the New York blizzard of March 12, 1888, when both the total fall of snow and rate of fall were much less but the wind exceeded 60 m.p.h. The synoptic situation of the 1888 blizzard, during which temperature fell below 5°F., was similar to the recent one, with a depression developing over the southern Atlantic States moving north-east and then north-north-east apparently under the influence of a depression over the Great Lakes.

OBITUARY

Mrs. A. H. R. Goldie. With deep regret we record the death on February 3, 1948, of Mrs. Goldie, wife of Dr. A. H. R. Goldie, Deputy Director (Research) of the Meteorological Office. To Dr. Goldie we extend the sympathy of all members of the staff of the Meteorological Office in his great loss.

Two friends of Mrs. Goldie, the one closely associated with her at Edinburgh and the second at Stonehouse during the war, have written appreciations which we publish below.

Mrs. Goldie's association with the Office dated back to August 1919 when, as Miss Marion Wilson, she joined the staff of Eskdalemuir Observatory with her friend Miss Graham-Yooll. After working there for a year under Dr. Crichton Mitchell, Superintendent, she was transferred to the newly-established Meteorological Office, Edinburgh, where she remained until her marriage to Dr. Goldie in 1928. Of a charming, friendly and happy disposition, Mrs. Goldie will be remembered by many members of the staff for her kindness and hospitality. One recalls delightful Christmas parties given to the staffs of M.O. Edinburgh and Scottish outstations.

A. E. MURRAY

The death of Mrs. Goldie will be keenly felt by all members of the Marine, Climatology and Instruments Branches who served at Stonehouse. Most of the younger members were billeted in strange homes, and Mrs. Goldie invited them to tea on Sundays, sympathised with their troubles and generally mothered them. I recall with gratitude that in an emergency the Goldies gave me a home for a week, and the same kindness was extended to visitors from London who could not find hotel accommodation. When the canteen arrangements broke down and we decided to become our own caterers, the triumphant success of the experiment was largely due to the energy which Mrs. Goldie put into it, in

addition to the work which she was already doing in the British Restaurant at Stroud. In all these ways, the fact that our exile in Gloucestershire was on the whole pleasant and comfortable, was largely due to the efforts of Dr. and Mrs. Goldie to make it so.

C. E. P. BROOKS

REVIEW

A numerical method for the calculation of temperature changes by radiation in the free atmosphere, by A. Bruinenberg. Koninlijk Nederlandsch Meteorologisch Instituut, De Bilt No. 125, Mededelingen en Verhandelingen, Serie B, Deel I. No. 1. Size: 12¼ in. × 8¾ in., pp. 103, *Illus.* 's-Gravenhage, 1947. Dutch with English Summary.

With the great increase in upper air observations the subject of non-adiabatic temperature changes in air masses is coming to the fore as an important problem in synoptic meteorology. Radiation is an example of such a process, and semi-empirical means of calculating the flux of radiation at a given level have been devised, the radiation charts of Mügge and Möller and of Elsasser being perhaps the best known. To compute the heat loss, however, the derivative of the flux is required, and readers familiar with the use of radiation charts will appreciate the difficulty and lack of precision involved in the plotting and estimation of long narrow areas of irregular shape. The greater part of the present memoir is concerned with the development of a direct numerical method for the estimation of the derivative of the flux, and with the presentation of the necessary tables and diagrams.

Chapters are devoted to a general survey of radiation problems, radiation charts—mainly a convenient transformation of the Möller chart, the determination of a change of flux with height by the method mentioned above, and direct heating of the atmosphere by solar radiation. The English summary concentrates on the original part of the work, and adequately explains the method. There are very helpful numerical examples. Tables and diagrams occupy 400 pages and represent a very considerable volume of work by the author.

No meteorologist interested in radiative temperature changes can afford to neglect this work, and the numerical method may prove more convenient than existing graphical ones for some problems. Results however will not be greatly different if the radiation charts are used with care ; the following figures may be quoted for one of the numerical examples. the first two figures being computed by Bruinenberg, the last by the reviewer.

De Bilt March 4, 1938, 1,100 to 1,200 m.
Cooling in 24 hr. (water vapour only)

Transformed Möller chart	1·8°C.
Numerical method	2·4°C.
" Kew " radiation chart	2·2°C.

G. D. ROBINSON

ERRATUM

FEBRUARY 1948, page 31, line 2, equation 14

$$\textit{for}\ \frac{lH_i}{T_0 - lH_i}\ \textit{read}\ \frac{lH_i^2}{T_0 - lH_i}$$

WEATHER OF FEBRUARY 1948

The month opened with a very deep depression in the Atlantic south of Iceland, with a reading of 936 mb. on the 2nd. Weather over the British Isles continued unsettled until about the 14th, when an anticyclone which had lain over eastern and north-central Europe since the 8th spread westwards. By the 16th it was centred over Scandinavia and easterly winds caused a rapid fall of temperature in Great Britain. The anticyclone again moved westwards to a position south-east of Iceland on the 22nd, after which it turned eastwards again to central Europe. For the month as a whole pressure exceeded 1020 mb. over England, southern Scandinavia and most of continental Europe ; another high-pressure area (1025 mb.) lay over New England, while the North Atlantic was occupied by a relatively low area (below 1010 mb.). Pressure was more than 5 mb. above normal over the British Isles, Scandinavia, northern France and the Baltic shores, the excess being 10 mb. over southern Norway, while the central Atlantic between 35° and 55°N. was slightly below normal.

The unsettled, stormy weather experienced in the British Isles throughout January persisted during the first half of February. Gales were reported locally on each day from the 1st-10th, the gale on the 8th-9th being both widespread and severe. The speed in gusts rose to 95 m.p.h. at Durham and 87 m.p.h. at Renfrew on the 9th. Heavy rain occurred in some areas on the 1st, 7th and 8th ; for example, 2.75 in. at Kinlochleven (Argyllshire) on the 1st and 2·97 in. at Bala (Merioneth) on the 8th. A change of type set in on the 15th and subsequently an anticyclone became centred over southern Scandinavia with an extension over the British Isles. Under the influence of this pressure distribution a cold air stream from north-east Europe brought cold, mainly fair weather to this country. On the 20th a cold front moving west over England and Wales was associated with widespread snow and on the 21st small secondaries moving west in the easterly current brought more snow to southern districts. Level snow was 14 in. at Biggin Hill, 11½ in. at Wilmington, Kent and 10 in. at Croydon, while at Hampstead there were drifts of three to four feet. It was very cold over much of England from the 20th-22nd, temperatures remaining continuously below freezing point at some places on the 20th and 21st. The last week was mainly sunny and dry ; except in foggy areas temperature rose on the 28th though the nights continued rather cold. In the southern half of England it was very warm on the 29th, temperatures reaching or exceeding 60° F. at many places. The extreme temperatures for the month were 64°F. at Milford, Surrey on the 29th and 5° F. at East Malling, Kent on the 22nd.

The general character of the weather is shown by the following table :—

	Air Temperature			Rainfall		Sunshine	
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average	Percentage of possible duration
	°F.	°F.	°F.	%		%	%
England and Wales	64	5	+0·8	73	−1	96	23
Scotland	55	15	+0·6	109	0	96	22
Northern Ireland ..	57	23	+0·5	81	+4	83	20

RAINFALL OF FEBRUARY 1948

Great Britain and Northern Ireland

County	Station	In.	Per cent of Av.	County	Station	In.	Per cent of Av.
London	Camden Square ..	1·40	84	*Glam.*	Cardiff, Penylan ..	2·38	81
Kent	Folkestone, Cherry Gdns.	1·25	62	*Pemb.*	St. Ann's Head ..	1·55	55
,,	Edenbridge, Falconhurst	2·60	118	*Card.*	Aberystwyth	1·05	42
Sussex	Compton, Compton Ho.	1·85	70	*Radnor*	Bir. W. W., Tyrmynydd	4·43	84
,,	Worthing, Beach Ho. Pk.	1·27	64	*Mont.*	Lake Vyrnwy	7·38	166
Hants.	Ventnor, Roy. Nat. Hos.	1·62	77	*Mer.*	Blaenau Festiniog ..	8·20	100
,,	Fordingbridge, Oaklands	1·08	43	*Carn.*	Llandudno	1·24	64
,,	Sherborne St. John ..	1·25	57	*Angl.*	Llanerchymedd ..	1·86	74
Herts.	Royston, Therfield Rec.	·84	55	*I. Man.*	Douglas, Boro' Cem. ..	2·93	92
Bucks.	Slough, Upton ..	1·06	62	*Wigtown*	Port William, Monreith	1·96	64
Oxford	Oxford, Radcliffe ..	·88	54	*Dumf.*	Dumfries, Crichton R.I.	3·48	106
N'hant.	Wellingboro', Swanspool	·91	57	,,	Eskdalemuir Obsy. ..	5·83	118
Essex	Shoeburyness	1·34	109	*Roxb.*	Kelso, Floors	1·64	96
Suffolk	Campsea Ashe, High Ho.	·83	60	*Peebles.*	Stobo Castle	3·45	125
,,	Lowestoft Sec. School ..	·71	51	*Berwick*	Marchmont House ..	1·69	81
,,	Bury St. Ed., Westley H.	1·04	69	*E. Loth.*	North Berwick Res. ..	1·93	124
Norfolk	Sandringham Ho. Gdns.	1·09	66	*Midl'n.*	Edinburgh, Blackf'd. H.	2·14	129
Wilts.	Bishops Cannings ..	1·25	59	*Lanark*	Hamilton W. W., T'nhill	3·99	138
Dorset	Creech Grange.. ..	1·68	59	*Ayr*	Colmonell, Knockdolian	2·11	81
,,	Beaminster, East St. ..	1·68	56	,,	Glen Afton, Ayr San. ..	5·13	117
Devon	Teignmouth, Den Gdns.	1·30	49	*Bute*	Rothesay, Ardencraig ..	5·18	129
,,	Cullompton	2·07	74	*Argyll*	L. Sunart, Glenborrodale	6·17	103
,,	Barnstaple, N. Dev. Ath.	1·17	43	,,	Poltalloch	5·19	120
,,	Okehampton, Uplands	2·67	61	,,	Inveraray Castle ..	9·57	141
Cornwall	Bude School House ..	1·34	54	,,	Islay, Eallabus ..	3·87	92
,,	Penzance, Morrab Gdns.	1·52	46	,,	Tiree	4·40	128
,,	St. Austell, Trevarna ..	1·68	44	*Kinross*	Loch Leven Sluice ..	4·09	145
,,	Scilly, Tresco Abbey ..	1·65	59	*Fife*	Leuchars Airfield ..	2·17	124
Glos.	Cirencester	1·49	66	*Perth*	Loch Dhu	10·90	146
Salop	Church Stretton ..	1·71	73	,,	Crieff, Strathearn Hyd.	5·73	163
,,	Cheswardine Hall ..	1·20	67	,,	Blair Castle Gardens ..	3·90	140
Staffs.	Leek, Wall Grange P.S.	1·78	75	*Angus*	Montrose, Sunnyside ..	2·16	117
Worcs.	Malvern, Free Library	1·11	62	*Aberd.*	Balmoral Castle Gdns...	3·03	117
Warwick	Birmingham, Edgbaston	1·61	95	,,	Dyce, Craibstone ..	1·04	45
Leics.	Thornton Reservoir ..	1·52	91	,,	Fyvie Castle	1·30	58
Lincs.	Boston, Skirbeck ..	·77	53	*Moray*	Gordon Castle	1·03	54
,,	Skegness, Marine Gdns.	1·14	75	*Nairn*	Nairn, Achareidh ..	1·78	110
Notts.	Mansfield, Carr Bank	1·35	70	*Inv's*	Loch Ness, Foyers ..	4·53	139
Ches.	Bidston Observatory ..	1·48	88	,,	Glenquoich	9·18	89
Lancs.	Manchester, Whit. Park	1·84	96	,,	Fort William, Teviot ..	8·51	113
,,	Stonyhurst College ..	3·58	107	,,	Skye, Duntuilm ..	4·43	96
,,	Blackpool	1·95	87	*R. & C.*	Ullapool	3·14	76
Yorks.	Wakefield, Clarence Pk.	1·51	88	,,	Applecross Gardens ..	5·38	107
,,	Hull, Pearson Park ..	1·10	66	,,	Achnashellach	7·66	111
,,	Felixkirk, Mt. St. John	1·12	66	,,	Stornoway Airfield ..	4·52	107
,,	York Museum	1·19	79	*Suth.*	Lairg	2·90	94
,,	Scarborough	1·13	67	,,	Loch More, Achfary ..	6·51	99
,,	Middlesbrough.. ..	·67	52	*Caith.*	Wick Airfield	2·29	101
,,	Baldersdale, Hury Res.	3·63	121	*Shet.*	Lerwick Observatory ..	3·54	112
Nor'd	Newcastle, Leazes Pk.	1·42	93	*Ferm.*	Crom Castle	2·34	80
,,	Bellingham, High Green	2·88	113	*Armagh*	Armagh Observatory ..	1·82	82
,,	Lilburn, Tower Gdns...	1·04	52	*Down*	Seaforde	2·20	72
Cumb.	Geltsdale	2·28	88	*Antrim*	Aldergrove Airfield ..	1·43	59
,,	Keswick, High Hill ..	5·16	104	,,	Ballymena, Harryville..	2·34	72
,,	Ravenglass, The Grove	2·47	80	*Lon.*	Garvagh, Moneydig ..	2·73	87
Mon.	Abergavenny, Larchfield	1·91	60	,,	Londonderry, Creggan	3·15	99
Glam.	Ystalyfera, Wern House	3·97	77	*Tyrone*	Omagh, Edenfel ..	2·99	100

CLIMATOLOGICAL TABLE FOR THE BRITISH COMMONWEALTH, OCTOBER 1947

Stations	Pressure		Temperatures							Relative humidity	Mean cloud amount	Precipitation			Bright Sunshine	
			Absolute		Mean values											
	Mean of day M.S.L.	Diff. from normal	Max.	Min.	Max.	Min.	½ Max. and Min.	Diff. from normal	Wet bulb			Total	Diff. from normal	Days	Daily mean	Percentage of possible
	mb.	mb.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	%	tenths	in.	in.		hrs.	%
London, Kew Observatory	1022·0	+7·8	70	32	59·5	43·5	51·5	+0·5	48·3	85	7·7	0·15	−1·55	4	3·0	28
Gibraltar	1017·7	+0·5	84	56	75·3	65·3	70·3	+3·9	66·6	86	5·2	1·64	—	6	—	—
Malta	1016·9	+0·9	82	58	76·4	64·3	70·3	−0·6	67·1	69	5·2	1·28	—	8	7·2	64
St. Helena	1017·0	—	68	52	62·0	53·7	57·9	+0·4	54·1	96	9·6	2·77	+1·46	23	—	—
Freetown, Sierra Leone	1011·9	+1·9	89	70	84·8	73·9	79·3	+0·8	75·0	85	7·9	14·38	+1·76	29	5·9	50
Lagos, Nigeria ..	1012·3	+1·3	91	67	86·7	70·6	78·7	−1·0	76·4	86	8·8	4·16	—	10	4·9	41
Kaduna, Nigeria ..	1010·6	—	93	59	88·9	65·3	77·1	−0·6	72·0	71	6·8	0·87	−1·88	4	7·8	65
Chileka, Nyasaland ..																
Salisbury, Rhodesia ..																
Cape Town ..	1017·4	0·0	83	46	69·2	55·3	62·3	+1·1	56·4	74	5·3	0·79	−0·86	8	—	—
Germiston, South Africa	1013·3	—	89	45	78·7	54·6	66·7	—	54·0	48	3·4	0·88	—	7	9·6	76
Mauritius	1020·5	+2·3	82	62	79·3	65·1	72·2	−0·5	65·1	70	5·2	0·68	−0·99	21	8·3	66
Calcutta, Alipore Obsy.	1009·7	+0·2	95	66	88·9	75·0	81·9	+2·6	75·6	88	5·3	3·27	−1·63	10	6·1	53
Bombay	1010·8	+1·0	93	71	87·6	74·6	81·1	−1·3	74·3	86	2·8	2·92	+1·25	3	8·9	76
Madras	1009·6	+0·7	93	69	88·5	74·6	81·5	−0·8	75·8	84	6·0	11·55	+0·40	16	7·1	60
Colombo, Ceylon ..	1011·5	+1·5	89	70	84·3	74·5	79·4	−1·1	74·8	88	8·2	11·41	−1·95	17	6·1	51
Singapore	1009·5	−0·2	91	72	87·3	74·6	80·9	−0·2	77·4	82	—	6·81	−1·26	21	—	—
Hongkong	1015·4	+1·7	88	65	80·2	70·0	75·1	−1·8	68·3	72	5·0	0·70	−4·24	6	7·7	66
Sydney, N.S.W. ..	1014·5	−0·3	85	48	71·9	55·6	63·7	+0·1	56·4	54	4·5	2·18	−0·67	9	7·6	59
Melbourne	1013·0	−1·8	84	41	65·8	48·3	57·1	−0·6	51·2	59	6·9	4·66	+2·03	19	5·5	42
Adelaide	1015·2	−0·8	87	43	67·1	51·1	59·1	−2·8	52·9	58	7·1	2·77	+1·03	17	5·4	42
Perth, W. Australia ..	1016·1	−0·7	79	40	69·7	50·8	60·3	−0·5	55·7	64	5·0	5·65	+3·43	16	7·6	59
Coolgardie	1014·4	−0·5	91	39	74·5	50·1	62·3	−1·4	51·3	54	2·7	0·69	+0·03	5	—	—
Brisbane	1016·9	+0·7	86	54	76·4	59·1	67·7	−2·1	60·3	63	6·0	3·66	+1·13	11	7·7	61
Hobart, Tasmania ..	1009·3	−1·0	82	37	60·8	45·1	52·9	−1·2	47·9	63	7·9	7·60	+5·34	24	5·9	45
Wellington, N.Z. ..	1011·6	−1·5	70	38	58·8	47·9	53·3	+0·3	50·9	80	8·6	7·61	+3·53	19	4·4	33
Suva, Fiji	1013·1	−0·1	84	63	81·3	70·6	75·9	+0·1	71·3	79	6·5	5·49	−2·80	14	6·7	54
Apia, Samoa ..	1010·6	−0·9	89	68	86·3	73·1	79·7	+1·3	76·1	73	5·8	7·59	+1·21	13	7·3	59
Kingston, Jamaica ..	1011·9	+0·4	93	72	89·6	72·3	80·9	+0·4	76·1	77	3·3	2·32	−5·14	6	8·8	75
Grenada, W. Indies ..	1011·4	+0·6	88	73	87·0	76·4	81·7	+1·6	78·4	80	6·4	4·49	−3·27	27	—	—
Toronto	1020·0	+2·5	79	34	67·0	48·0	57·5	+8·9	48·7	84	4·6	1·12	−1·45	5	7·0	63
Winnipeg	1012·5	−2·4	75	22	60·1	39·9	50·0	+9·3	40·0	82	5·4	1·58	+0·21	10	5·5	51
St. John, N.B. ..	1017·9	+2·1	76	30	60·5	44·0	52·3	+7·0	43·2	84	5·0	0·27	−4·27	6	6·7	61
Victoria, B.C. ..	1010·8	−6·3	73	33	57·1	43·1	50·1	−0·2	46·1	94	7·5	6·03	+3·46	19	3·2	29